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LIME AND FERTILIZER STRATEGIES FOR FORAGE PRODUCTION

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A sustainable cattle industry depends on economical production of forage grasses and legumes. However, recent trends involving higher fuel prices that affect equipment operation, transportation, production inputs, haying, and marketing are causing increasing concern about the economies of forage and livestock production. The forage and livestock production gamble is increasing. Although producers may not directly use natural gas to power their equipment, their bottom line is affected by the increasing cost of this fuel for producing nitrogen (N) fertilizer.

Natural gas is used to make anhydrous ammonia (NH₃) N. In the synthesis of NH₃, air that contains 78% N is reacted with natural gas (methane, CH₄) under high temperature and steam pressure with a catalyst to produce NH₃ and carbon dioxide (CO₂). Ammonia is the starting material for manufacture of most other N fertilizers.

Since 1999, the increasing price of natural gas caused permanent shut down of 25 US ammonia plants and idled several more because economical ammonia production could not be sustained. As ammonia plants shut down, fertilizer imports have increased to more than 50% of usage in the US.

Fertilizer prices

Because of the increasing costs of fuel for transportation, natural gas for manufacturing, and greater international demand, the cost of commercial fertilizers has more than doubled since the year 2000. Recent data indicate rapid escalation of fertilizer prices. Most N fertilizers are up more than 130% over the past several years. Diammonium phosphate (18-46-0), the phosphorus source used in fertilizer blends, currently retails for at least $1,000/ton; potash (0-0-60) fertilizer costs $600/ton, or $0.50/lb of K₂O and is predicted to increase even more by 2009; sulfur (S) recently increased by $250 to sell
for $625/ton and it is expected to increase another $125/ton in the third quarter of 2008.

With the rapidly increasing prices of fertilizers, it has become even more important for farmers and ranchers to know the cost of inputs for forage crops and other crops production. Pricing fertilizer by the pound of plant nutrient contained in a ton allows one to know the cost of the plant nutrients applied.

The adjacent chart shows the value per pound of N contained in a ton of selected N sources and potash available for application on forage grasses as of April 7, 2008. The percentage N in each material is shown with the cost per ton and the cost per pound of N in each ton. The price of the N fertilizers ranges from $340 to $500/ton. The price per ton is higher for the more concentrated N sources, but on a price per pound of N basis, the cost range is not as great. By knowing the price per pound, it becomes easier for producers to determine the lowest priced N material. So, how do we determine the price per pound of nutrient?

**Calculating the cost/lb of N**

By knowing the cost per ton and the N percentage in an N fertilizer material, such as urea, the cost per pound of N can be calculated. First, convert the percentage N to a decimal fraction by dividing by 100. Multiply the decimal fraction by 2000 lb/ton. The amount of N in a ton of urea is 920 lb. Divide the cost/ton by the amount of N in each ton to find the cost/lb of N. If it is not already included in the price per ton, fertilizer spreading is added.
venders charge for spreading. In the example above, the spreading fee is $5.00/ac for driving the spreader truck over the field. In this example the N rate is 70 lb/ac. Dividing the per-acre spreading fee by the N rate being applied determines that spreading adds 7 cents/lb to the N. So the cost of N applied to the field is $0.614 lb. The amount of N applied multiplied by the cost of N/lb determines the total cost of N. In this example it is $42.98/ac. Similar calculations can be done for other N fertilizers. For ammonium nitrate selling at $440/ton with a spreading fee of $4.00/ac, 70 lb of N costs $49.28/ac.

The same approach can be used to determine the cost lb of potash (K$_2$O) applied/ac. Potash is 60% K$_2$O, or 0-0-60 for the red colored material. Convert the 60% to the decimal fraction and multiply that fraction by 2000 lb/ton to determine that a ton of potash contains 1200 lb K$_2$O. Divide the $600 cost/ton of potash by the pounds of K$_2$O/ton to determine that each pound of K$_2$O costs $0.50/lb before adding the spreading cost. Rarely is potash applied by itself; it usually is applied in blend with other plant nutrients, so the cost of spreading is more difficult to determine for individual nutrients in a blend.

At low to moderate N rates, urea is not as effective as is ammonium nitrate or ammonium sulfate for grass production. In N-rate studies conducted by AgriLife Research scientists at Overton, urea and urea-ammonium nitrate produced 14 and 20%, respectively, lower Coastal bermudagrass yields compared to ammonium nitrate at the 40 lb N/ac rate/cutting for 3 to 5 cuttings. Ammonium sulfate produced equal yields compared to ammonium nitrate at the 40 lb/ac N rate. Yield differences between N sources generally decline as the N rate is increased.

The pounds of forage produced per pound of N applied decreases as the N rate is increased. However, in haying situations, crude protein in forage receiving the lower N rates on N-deficient soil will be low and additional N is needed if higher nutritive value forage is desired.

The increasing cost of energy and natural gas to manufacture N fertilizers is directing some companies toward use of lower production energy requiring fertilizers such as urea. However, urea and urea-containing N fertilizers lose N as ammonia gas by a process called volatilization when these materials are applied and left on the soil surface. Companies are working to develop materials that delay conversion of urea to ammonia and prevent volatilization losses. These
products include coatings and inhibitors that delay the activity of urease, an enzyme responsible for converting urea to the ammonia gas, or by delaying conversion of the ammonium form of N to the nitrate form. Texas AgriLife Research scientists are evaluating some of these materials in cooperation with manufacturers. Agrotain, Nutrisphere (NSN), Environmentally Smart N (ESN), calcium thiosulfate, and sulfur coated urea are some of the materials being evaluated and may be available at ag chemical companies or urea or urea-ammonium nitrate fertilizer distributors.

**Production strategies**

The forage and livestock production gamble is changing and the old rules are becoming even more important. Soil testing is critically important to determine the residual fertility levels of soil in order to prevent unneeded fertilizer application. The need to maintain an adequate pH by liming acid soils for forage production cannot be over-emphasized, and the limestone should be incorporated when possible. The fertility strategy must be re-evaluated- will it pay to apply limestone and fertilizer? How much can be applied and still be economical? If the fertilizer and limestone input is reduced, be prepared to lower the stocking rate because of lower forage production. Use alternative nutrient sources such as broiler litter and other manures if these are available and if they are economical to apply. Make certain that any alternative nutrient source being considered actually is a reliable source of plant nutrients, and not some fly-by-night, watered down material supported only by testimonials i.e., “For only $25/gallon and applied at the rate of 1.0 gal/ac, company X’s material will produce the same forage yield as will the fertilizer recommended by soil test.” Don’t even try these types of materials claimed as all-purpose miracle fertilizers.

Forages take up definite amounts of the 16 essential plant nutrients. Average season-long nutrient uptake by Tifton 85 bermudagrass under hay production conditions includes 368 lb of nitrogen, 33 lb of phosphorus, 325 lb of potassium, 53 lb of calcium, 19 lb of magnesium, 60 lb of sulfur/ac, and smaller amounts of the micronutrients including zinc, copper, iron, manganese, boron, molybdenum, and chloride. If these are not available in soil, they must be applied as fertilizer, limestone, or in the case of N, by legumes, or the desired amount of grass will not be produced. No soil activator
or foliar-applied material sprayed at a gallon/ac is going to provide these amounts of nutrients to grass.

The image of a soil test report on the previous page is shown to indicate that soil testing is very important and that the recommendation for needed limestone is made based on application of 100% effective limestone, described as Effective Calcium Carbonate Equivalence and abbreviated as ECCE.

**Limestone quality and economics**

Quality of limestone begins at the quarry where it is crushed and screened. Pure limestone has a calcium carbonate equivalence (CCE), or neutralizing value, of 100%. The ECCE is determined by passing the crushed limestone through a series of sieves.

Efficiency factors are assigned to limestone fractions on each sieve. Material passing a 60-mesh sieve is considered 100% efficient for totally reacting in three years. The greater the ECCE % of the limestone, the more rapidly it will react, and less limestone will be needed to change soil pH.

The increased efficiency of ECCE 100% limestone is shown in the chart below. Limestone with ECCE 62, 81, and 100% was applied to Darco soil and left on the surface at rates of 0, 1, 2, and 3 tons/ac. Crimson clover yields were measured on these plots two and one-half years later. Three tons ECCE 62% limestone was required to optimize clover dry matter compared to two tons/ac for ECCE 81%, and only one ton of ECCE 100% was needed to produce the same yield. Additionally, the ECCE 100% limestone maintains a higher pH over a longer time because the finer limestone more fully reacts to neutralize soil acidity and raise pH to a higher level than does the coarser limestone. In a long-term study, soil pH remained 0.3 units higher from ECCE 100% limestone compared to ECCE 62% when both materials were applied seven years earlier at 0, 3, and 6 ton/ac.
Application of the more efficient, high ECCE % limestone is more economical than applying the coarser, lower ECCE % materials. The argument for this is presented in the adjacent chart. If the soil test recommends application of 1.0 ton of ECCE 100% limestone/ac, that one ton will contain 2000 lb of effective liming material (ELM). If the choices of limestone to apply are ECCE 62% at a cost of $42/ton, and ECCE 100% at a cost of $45/ton, application of one ton of ECCE 100% limestone/ac will cost $45. However, if the ECCE 100% is not available, or your local limestone vendor doesn’t handle it, the recommended rate using a lower quality limestone such as ECCE 62% must be adjusted. This is done by dividing 100% by 62%, as shown, and applying that adjustment factor to determine the rate of ECCE 62% limestone/ac. Using ECCE 62% limestone increases the cost/ac from $45 for the ECCE 100% limestone to $67.74 when using the ECCE 62% material. Applying 62% limestone increases the liming cost by $22.74/ac. This is a significant cost increase that can be avoided by locating a limestone supplier who is willing to spread the ECCE 100% material.

Two Texas quarries are listed in the chart to the right. These companies each have an ECCE 99% limestone that contains about 4% magnesium (Mg). One company also makes an ECCE 63% limestone that sometimes is referred to as ag-grade limestone. Several companies in Oklahoma also sell limestone into northeast Texas. Each of these Oklahoma companies has coarse limestone, but the one at Mill Creek, OK also makes high ECCE calcitic and dolomitic limestones. Pure dolomitic limestone contains about 13.1% Mg, and at equal particle size is slower reacting than is calcitic limestone. Acid soils that need limestone in Texas are usually low in Mg and benefit from application of Mg in limestone.

Nitrogen in the ammonium form applied to the low-buffer capacity, acid soils causes increased acidity. This occurs when the ammonium is converted to nitrate. The slide below shows a decline in pH at the lower left from 5.4 to 4.5 after three years of N application at rates
200 lb/ac/year when no limestone was applied. As the rate of limestone was increased from zero to 2.0 ton/ac on the lower right axis, the acidifying effect of the applied N becomes less. The pH change at the high rate of limestone and three years of applying 200 lb of N/ac each year is only 0.2 pH units lower compared to pH at the high rate of limestone with no N applied.

Conversion of ammonium in anhydrous ammonia, urea, ammonium nitrate, and urea ammonium nitrate to nitrate in the soil increases acidity that requires 1.8 lb of additional limestone to neutralize the acidity for each pound of N applied. The acidity generated by nitrification of ammonium in ammonium sulfate and diammonium phosphate is even greater. When fertilizing with nitrogen, it is important to take soil samples at least every two years to monitor soil acidity levels and maintain pH in the range favorable for forages on acid soils.

The chart at right expands one shown earlier and shows the eventual cost/lb for five N sources applied at a rate of 100 lb of N/ac. The cost of limestone to neutralize the acidity has been added to the cost/lb of N and spreading costs. For forage production on low-buffer capacity, acid sandy soils, the cost of 100 lb of N ranges from $71 to $100 based on April 2008 prices.

Annual ryegrass, like many grasses and legumes, is sensitive to soil acidity. As soils become increasingly acidic at pH 5.5 and lower, aluminum rapidly increases in solubility (See
Aluminum in sufficient concentrations is toxic to acid-sensitive plant roots and prevents these roots from growing and exploring the soil mass for water and nutrients. The consequence is acidity-induced yield reduction. The solution is to lime acid soils to maintain pH above 5.5 for forage production. The favorable pH can vary by crop, but is considered to be about 6.0 to 6.2 for most forages. Alfalfa and Tifton 85 bermudagrass are two exceptions that continue to increase yield at soil pH levels near 7.0.

The image at the left shows arrowleaf clover response to limestone and boron applied to field research plots. Clovers need limed soils in order for the Rhizobia on the roots to thrive and fix adequate amounts of N for the plants.

The image below graphically shows Tifton 85 response to soil pH on the lower right and to poultry litter rates on the lower left. Yield is indicated on the left vertical line. Data from Tifton 85 response to increasing pH was interpreted and put into the table at the lower right to show the projected yield increase at increasing pH and the value of that increased yield beginning at different pH levels. For example, at soil pH 4.5 in the left column, bermudagrass hay yield was 10,071 lb/ac. When the soil was limed to pH 5.0, hay yield increased 783 lb and its gross value increased $39.15/ac when hay was valued at $100/ton. When pH was increased to 6.5, yield was
raised by 3.133 lb/ac and gross value of that higher yield was $156.65/ac. Yield and gross hay value increases due to liming also are shown for beginning soil pH values of 5.0 and 5.5.

Annual ryegrass response to limestone is shown in the adjacent image. The darker colored taller growth was the result of liming Lilbert loamy fine sand to pH 6.2 using 1.7 tons of ECCE 62% limestone/ac disked into the soil. Initial soil pH of the unlimed area with the much shorter grass was 4.5.

Yield and soil pH change data from this limestone-rate ryegrass study were collected for three growing seasons. Dry matter yield (middle chart) increased 1.30, 1.99, and 2.39 tons/ac in the three seasons, or a total of 5.68 tons in the limestone treated plots compared to the unlimed, pH 4.5 soil at equal N, phosphorus, and potassium rates. The ECCE 62% limestone, even when it was disked into the soil, needed two years to maximize pH to its highest level of 6.2.

With limestone applied at the rate of 0.3 tons/ac, there was little change in soil pH, from 4.5 to 4.7 the second season. By the third season, soils treated with the 0.3 ton/ac rate declined to pH 5.5, similar to the unlimed plots.

The adjacent chart uses the ryegrass yield increase from the limed plots and projects weight gain and value of that additional forage if it were grazed by stocker steers. The increased value of the weight gain is then related to the cost of the limestone applied on a per acre basis. The net value of the weight gain after subtracting the value of liming acid 50115 for ryegrass production?

5.68 t/ac dry matter increase in 3 seasons

The value of liming acid soils for ryegrass production?

Effect of limestone on soil pH and ryegrass dry matter yield on Lilbert loamy fine sand:

<table>
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<tr>
<th>Lime rate</th>
<th>pH year 1</th>
<th>DM year 1</th>
<th>pH year 2</th>
<th>DM year 2</th>
<th>pH year 3</th>
<th>DM year 3</th>
<th>pH year 4</th>
<th>DM year 4</th>
</tr>
</thead>
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<td>0</td>
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<td>1.39</td>
<td>4.5</td>
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<td>0.32</td>
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</tr>
<tr>
<td>0.3</td>
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<td>2.26</td>
<td>4.7</td>
<td>2.29</td>
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<tr>
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<td>5.7</td>
<td>2.69</td>
<td>6.2</td>
<td>3.71</td>
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</tr>
</tbody>
</table>

Data from Dr. Jeff Hillard's dissertation, Texas Agricultural Experiment Station, 1988.

5.68 t/ac dry matter increase in 3 seasons
limestone costs is $214.87/ac per season, or a three-season total of $716/ac. This shows the value of limestone applied at 1.7 tons per acre at a cost of $71.40. If ECCE 100% limestone had been used, net income would have been even greater as less of the higher quality limestone would have been applied to achieve the same pH.

The value of the protein in the increased ryegrass yield is calculated in the adjacent chart by comparing it to 38% protein cubes at a cost of $330/ton. Ryegrass was assumed to contain 15% crude protein, but the actual value would be higher. The value of ryegrass compared to 38% protein cubes is calculated to be $450/ac for the three ryegrass production seasons, or $150/ac per year. The previous slide regarding stocker steers grazing ryegrass and this slide comparing ryegrass protein to 38% protein cubes show the increased value of ryegrass produced on an acid soil that was adequately limed compared to not liming the soil. These calculations show that liming acid soils generates a good return on the investment.

Similar values as shown for limestone and ryegrass production could be projected for increased crimson clover yield from limestone applied to a strongly acid Darco soil as shown in the middle slide.

The slide to the right shows the response of alfalfa to limestone and boron on Darco soil. Where limestone and boron were not applied, there was no alfalfa, and where limestone was applied to increase soil pH to above 7.0 and boron was applied at 4 lb/ac, there was an excellent stand and increased alfalfa yield.
The chart at right shows the increased alfalfa yield and the value of this increased yield. Increasing soil pH from 6.0 to 6.5 increased hay yield 1.08 tons/ac valued at $146 with hay priced at $135/ton. When soil pH was increased to 7.0, the 1.94 ton/ac increased hay yield was valued at $262. Only 1.5 tons of limestone/ac would adjust pH from 6.0 to 7.0 on Darco soil. At a cost of $45/ton of ECCE 100% limestone, 1.5 tons would cost $67.50/ac while the alfalfa yield increase for only one season was valued at $262, or a net increase in income from liming to pH 7.0 of $194/ac. Soil pH declines more slowly under alfalfa production than when N fertilizer is applied because Rhizobia fix atmospheric N and put it directly into the roots without the N needing to be converted to nitrate and acidifying the soil in the conversion process.

Results showing the increased yield and value of forages due to liming acid soils indicate the importance and economic value of this practice. When fertilizer prices are high and producers are hesitant to apply these plant nutrients, liming acid soils to improve plant nutrient efficiency and response of acid sensitive forage crops increases the value of this acid-neutralizing primary input. Fertilizers applied to strongly acidic soils are less efficient than when applied to adequately limed soils. This has been proven many times and several examples of this improved efficiency have been presented in this manuscript.

**Nitrogen fertilization for grass forages**

Nitrogen in forage grasses is the most highly concentrated plant nutrient. Numerous studies of fertilizer N and grass production have been conducted. Three studies on hybrid bermudagrasses are reported here to show the yield response and net dollar return from increasing fertilizer rates.

In the chart below, increasing the rate of applied N from zero to 45 and 90 lb/ac for each regrowth increased Tifton 85 bermudagrass hay yield from 3.748 lb to 12.591 and 16.253 lb/ac, respectively. If this hay was valued at $100/ton (even with no added N), the zero N treated grass value was $187/acre compared to $442 and $625/acre gross value for hay fertilized with 180 and 360 lb of N/ac in four split applications, respectively, or a gross increase for the fertilized hay of $255 and $438/acre. When the cost of the applied N was deducted from the gross value of the hay, the
net increases in hay value due to fertilizing with N were $122 and $188/ac, respectively. At the 180 lb/ac rate, each pound of applied N produced 50 lb of hay/ac. When the N rate was doubled, hay yield per dollar invested in N declined to 35 pounds.

A similar study was conducted on Coastal bermudagrass using zero, 40, 80, and 120 lb of N/ac per hay cutting. Hay yield with no applied N was about 3.5 tons/ac, and at $90/ton, was valued at $310/ac. As the total N rate was increased to 200, 400, and 600 lb/ac for the season, total hay yield increased to 12,309, 15,134, and 15,844 lb/ac, respectively. The increased gross value of this hay compared to the zero N hay yield was $244, $371, and $403/ac. When the cost of N applied at $0.65/lb plus a $4.00/ac spreading fee was subtracted from the gross value of the produced hay, applications of 40 and 80 lb of N/ac per regrowth produced similar net income. Applying 120 lb of N/ac per cutting lost money because this highest N rate produced only a small amount of increased hay compared to the 80 lb N/ac rate. These N-rate comparisons on Tifton 85 and Coastal bermudagrass do not include haying costs or applied P, K.

The cost of haying is added in the chart at right. In this study, yield with no applied N was only 3 tons/ac. The first 180 lb of N/ac increased hay yield to 7.1 tons/ac. The 360 lb/ac N rate raised yield another 1.6 tons/ac, but the yield increase/lb of N declined. Even with the cost of haying included.
with the cost of N, yields appear to be economical, especially up to the 80 lb N/ac rate applied for four cuttings to yield 8.7 tons of hay/ac.

Since many Coastal Plain soils are deficient in P or K, the cost of these nutrients must be added along with the N. The cost of a typical N, P<sub>2</sub>O<sub>5</sub>, and K<sub>2</sub>O blend applied at 40 or 80 lb N/ac/cutting for four harvests is shown at right. Assuming that the hay yield was the same as in the previous chart when the phosphorus and potassium were added, that chart is repeated here with new fertilizer plus haying costs indicated. With the costs of N, P, K and haying included, the economic rate of return on hay is not much above the 190 lb/ac application of 21-8-17/cutting. At double this rate, the cost of production exceeds the value of the hay sold at $90/ton. Based on these data, the days of fertilizing hybrid bermudagrasses for maximum hay yield may be past; at least as long as fertilizer prices remain high and continue to increase and hay prices remain the same.

**Legitimate alternative plant nutrient sources**

With the high cost of commercial fertilizers, forage producers need to evaluate alternative sources of plant nutrients such as in animal manures and lime-treated, stabilized sewage sludge (biosolids). National and international studies have shown the value of biosolids for increasing soil phosphorus
content and raising pH and forage yield.

Animal manures probably were the first plant nutrient sources used for crop production. Poultry manures are routinely applied for forage production in eastern and east central Texas. Dairy manures are available in northeast Texas and parts of central Texas, but mainly are applied on-farm because of transportation costs. The average N, P₂O₅, and K₂O contents of dairy, beef, hogs, and chickens is shown in the top chart.

Broiler litter is available in much of the eastern and central Texas region and is a good source of plant nutrients for forages. However, as commercial fertilizer prices continue to increase and more forage growers turn to broiler litter as a plant nutrient source, longer wait times are being experienced before this material can be delivered.

In broiler litter, phosphorus is nearly as high as is the N content. If broiler litter is applied at rates sufficient to satisfy the N needs of grass forages, the soil phosphorus level will increase. When fertilizing with broiler litter, it is best to apply rates that will satisfy the phosphorus needs of the forage, and then supplement the grass with N and potassium to obtain the recommended levels of these nutrients for plant uptake. Data from Tifton 85 bermudagrass production studies at Overton indicate yield increases of more than 4,000 lb of dry matter when broiler litter was applied as a nutrient source. Even with increasing yields, average N, P, K, and copper concentrations were increased in the forage.

Advantages and disadvantages of using broiler litter as a plant nutrient source for forages production are shown in the adjacent chart. One of the greatest benefits of broiler litter is that it contains some of all the nutrients needed for plant growth, even though these may not be sufficient to supply all the needs of the plants.
Summary

In summary, fertilizer costs are continuing to increase with little hope for a significant decline in the immediate future. It has become more important than ever to be attentive to the best management practices in an effort to maintain profitability in forage and livestock production. Specific attention must be given to:

- Maintaining adequate soil pH using the best quality limestone available
- Control weeds at an early growth stage- weeds use water and nutrients.
- Maintain a fertilizer program.
  - Carefully consider the economics of not fertilizing.
  - Fertilize according to soil test recommendations.
  - Fertilize for grazing- cut excess for hay; buy hay.
  - Fertilize in late summer to stock-pile reserve forage for fall and winter grazing.
  - When reducing fertilizer application rates, reduce livestock numbers.
  - Research least-cost fertilizer options including broiler litter and other manure nutrients.
  - Consider renting buggies to apply fertilizer if economical and time and equipment permit.
- Plant and graze cool-season clovers to provide part of the following warm-season grass N needs.
- Consider growing alfalfa for hay if soils are suitable- alfalfa uses Rhizobia-fixed N from the air and adds N to the soil.
- Seed best soils to small grains and ryegrass in fall.
  - Plant reduced acres and maintain an adequate fertilizer and liming program on these acres.
  - Limit graze cow/calf pairs a couple of hours per day- feed high nutritive value hay.